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Interpreting the condition of the forest environment with use of the SCP/MIB model of carabid communities (Coleoptera: Carabidae)

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The paper presents the construction of the SCP/MIB model aimed at description of carabid communities during the production cycle of a forest stand, and in the course of regression changes occurring triggered by disturbance and stressing factors.

Key words: Coleoptera, Carabidae, carabid communities, forest environment.

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INTRODUCTION

Predatory Coleoptera belonging to the Coleoptera family (Coleoptera, Carabidae) are considered one of the most commonly occurring epigeic invertebrates of our forests. When studying the Polish carabidological literature, one may easily notice the growing application of carabids as zooindicators of the condition of both the forest environment, and the open area environment (Lesniak 1963, 1981, 1986, Sklodowski 1994a, 1994 b, 1995a, 1995b, 1995c, 1995d, Szwerk 2008, Schwerk and Szyszko 2008, Szujecki et al 1977, 1983, 1985, 1990, 1991, 2003, 2006 a, 2006b, 2008, Szyszko 1974, 1981, 1983, 1984, 1986a, 1986b, 1990, 1991, 1995, Szyszko 1996, 2000).

With the development of a foreststand, there changes also the species composition of its carabid communities. Eurytopic species and the species of the open terrain, both groups characteristic for the cultures and coppices, become replaced by forest species, often wingless and bigger, in the older forest stands. Moreover, part of the representatives of the spring developmental type withdraw for the benefit of the species representing the autumn developmental type. Similar is the process with the Holarctis and Palearctic species which, dominating in the communities living in cultures and coppices, are being replaced with age of the stands by representatives of the more „local" type species – those connected with Europe, the Caucasus, or Siberia.

The mean individual biomass - MIB index value of carabid communities grows as the forest stands develop (Szyszko 1983, 1990). The value of the index despite its evidently positive correlation with the age of environment, may, however, be subject to substantial year-by-year change (Sklodowski 1995a). The potential for the interpretation of the forest environment condition supplied with the MIB index is indisputable. In

order to construct the model describing the change either regressive or progressive of a carabid community in two directions, it is necessary however to get one more index such that would be similarly correlated with the age of the stand. It came out that it is possible to elaborate such an index: it was called the Progressive Features Sum SCP.

CONSTRUCTING THE INDEX OF PROGRESSIVE FEATURES SUM SCP

The index has been constructed based on the proportion in the community of those carabid groups that predominate the old growth forest stands. Below there is listed the complete group set:

- The species belonging to the autumn developmental type that is, those that spend winter in the form of larvae, and their activity peaks in the second half of the year. Grüm (1976) has proven that in those carabid communities that contain mainly the autumn type species (in the contrary to those with the spring type species prevailing) large part of the assimilated matter has become incorporated into the biomass and is further used by higher rank consumers with smaller loss of energy per unit of newly produced biomass. So far lots of observations have been carried out suggesting the growing proportion of this group together with the growing age of the forest stand (Szyszko 1974, 1983, 1990, Szujecki et al 1993, Sklodowski 1995a, d).

- Forest species that dominate in the middle-aged to old growth forest stands (Szyszko 1983, 1990, Szujecki et al. 1993, Sklodowski 1995a, 1995d).

- Large zoophages (individual body mass > 100mg), large sized Carabidae species representatives appear in a greater number only after the crowns get closed. Their proportion grows together with the age of the stand (Szyszko 1974, 1983, 1990, Szujecki et al. 1993, Lesniak 1981, 1986, Sklodowski 1995a, 1995d).

- The species characteristic of a limited distribution range in the northern Hemisphere, as compared with the Holarctic and Palearctic distribution ranges – that is: European, Central European, European-Siberian and Caucasus-European. The discrimination of this group was enforced by the observations results suggesting the growing shares of representatives of the limited distribution range species together with the growing of the forest stand, as performed in the northern Hemisphere's carabid communities (Szyszko 1974, 1983, Szujecki et al. 1983, Sklodowski 1995a). Another rationale for the identification of this new group was the location of the geographical distribution ranges limited to the narrow belt of small temperatures amplitudes, this fact suggesting the higher specialization of the group's species.

The SCP index has been constructed as the sum of shares in the community of the above listed Carabidae groups. The SCP index is strongly positively correlated with the age of the forest stands where the group species live (Fig. 1):

$$Y = 74.9 + 102 * LOG(X)$$

$r>0.93$ $p<0.0001$, $n=76$

where: Y – the SCP index value, X – the age of the stand. The value of the carabid communities SCP index increases with the age of the forest stand, but the increase itself in uneven. The highest increment of the index value is observed in the initial 20 years of the Scots pine forests. This is the age when the crowns get closed, which creates the condition favorable for colonization of the still young forest by those forest Carabidae species that are characterized not only by the larger values of the MIB index but also, the growing shares of the groups used for the construction of the SCP index. In stands aged more than 20 years, the intensity of SCP index increment slightly diminishes. This is the age when Scots pine forest stands are subject to several silvicultural intervention activities that result in, among other things, the loosening of the crowns enclosure which, in turn, limits the developmental potential for the carabid communities.

Theoretically, the SCP index may reach the maximum value equal 400 units. This is equivalent of the highest MIB index values found in the highest organized Carabidae communities (the MIB index very rarely exceeds the level of 400mg - Sklodowski 1995a, Szyszko1995). The growing values of the both indices as observed with the age of forest stand, and their convergence, may be described by the following correlation formula:

SCP = - 151.2 + 169.9*LG(MIB) r=0.88 P=0.0001.

By grouping the two indices in one plain using two perpendicular axes XY, the SCP/MIB model of successional development of Carabidae communities is constructed (Fig.2). In this model, four age groups of forest stands are included: the cultures (5-year old), the coppices (10-year old), the premature (40-year old) and the mature stands (80-120 year old). In the younger stands it is the SCP index that is characterized by higher variability while in the older stands – the MIB index is more varying.

The distances between particular points are in fact the distances informing about the development of carabid communities eg within the entire production cycle of the forest stand (from the culture till the old-growth stand), the distance may also be interpreted in the terms of the regression degree of given communities resulting from the felling of the old-growth forest stand (from the mature stand till the culture). The length of the vector may be determined by using the formula (below) which was produced by applying the cosine rule transformation:

The length of distance =

$$\sqrt{(y2 - y1)(y2 - y1)+(x2 - x1)(x2 - x1)}$$

where: y2, y1, x2 and x1 denote the respective co-ordinates of the SCP/MIB index.

Such a distance, being actually merely a vector on the plain, may be directed to a number of directions therefore, in order to univocally describe it, the angle between the directed vector itself and the OX axis needs to be included but this may be performed in a number of ways, with simply use of one of the trigonometric formulas.

EXAMPLES OF USING THE SCP/MIB MODEL FOR THE INTERPRETATION OF THE DEVELOPMENTAL STATUS OF CARABIDAE COMMUNITIES AND THE CONDITION OF THE FOREST ENVIRONMENT

The development of Carabidae communities in the course of the production cycle of Scots pine forest stands in the forest soil and non-forest soil

Fig.3 shows the SCP/MIB coordinates responsible for the carabid communities in unevenaged forest stands growing on forest soil (F1-F5) and in abandoned post agricultural ground (A-A1-A6, Skłodowski 1995a). The final "forest" community F5 is situated in the right hand uppermost part of the graph. The diminuting distances between particular communities: F1-F4 and C-C6, and the final F5 community give the evidence for the gradual development of the carabid communities with age of the forest stand (table 1).

The F1 community (table 1, Fig. 3) of the cultures established on a clearcut area transforms within

Table 1. Distances between the final community F5 and the other considered communities. The distances (vector lengths) were calculated using the Sklodowski (1995a) formula

Arable soil	Forest soil
A 349,44	
A1 338.14	F1 322,20
A2 344,53	F2 309,67
A3 216,72	F3 288,98
A4 88,96	F4 143,83
A5 137,00	
A6 109,06	

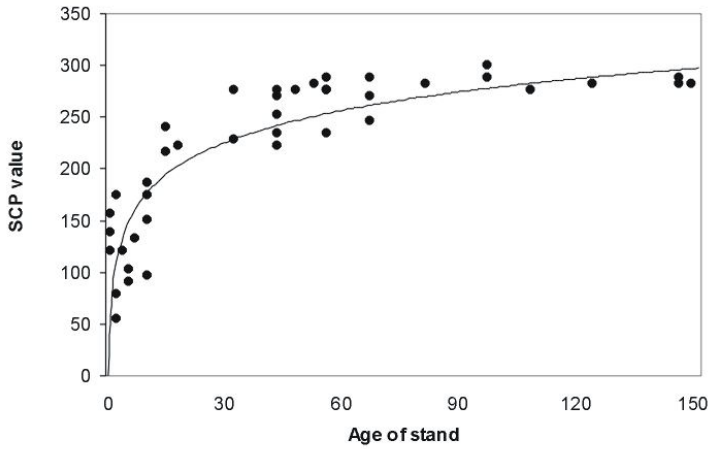

Fig. 1. Correlation between values of SCP index of Carabids beetles and age of inhabiting forests.

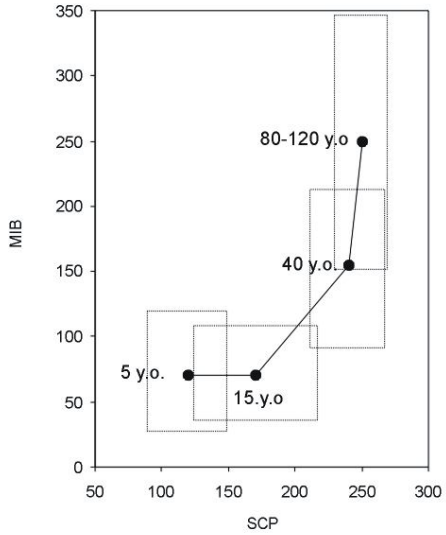

Fig. 2. The SCP/MIB model presenting the development of the Carabidae communities in pine management forests (5-years old – the cultures, 15-years old – the coppices, 40-years old – the premature stands and 80-120-years old – the mature stands). The rectangles denote area of standard deviations of the values of SCP index.

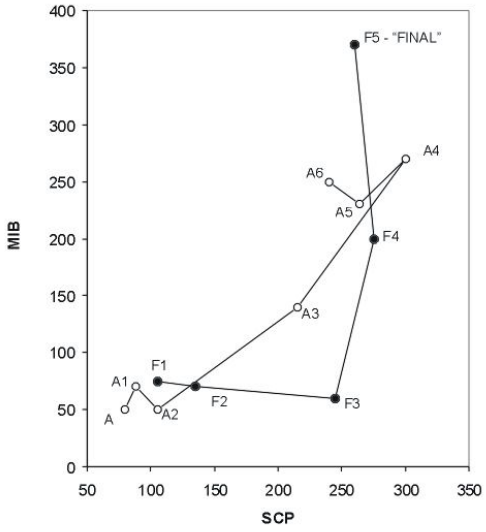

Fig. 3. The SCP/MIB model presenting the development of the Carabidae communities as taking part in the course of the Scots pine forest stands production cycle, in the post arable ground (dotted line) and in the forest soil (solid line).

Denotations

I. Post arable grounds: A – arable ground, A1 - 2-6-year old forest cultures, A2 - 8-14 year old coppices, Pdc3 - 18-year old coppices, A4 - 25-year-old forest stands, A5 - 33-62-year old forest stands, A6 – old growth (98-year old) forest stands.

II. Forest grounds: F1 - 2-3- year old forest cultures, F2 - 6-11- year old coppices, F3 - 18 22-year old forest stands, F4 - 25-42- year old forest stands, F5 - 62-98 year old forest stands.

a couple of years into the „F2" community, occupying 6-11 year old coppices, which is equivalent of the vector of length equal 32.58 units, between the points F1 and F2, at the angle of 352°. Such an angle means a slight reduction in the index MIB value, because despite the change of codominant species, the large non forest zoophage *Broscus cephalotes* (F1 13.3%) was replaced in the „F2" by other large zoophages – the forest species *Carabus arcensis* (9.45%). On position 4 in the dominance structure list of the F2 community there is present another forest related carabid species: *Calathus micropterus*.

The transformation process of the F2 community into F3 (18-22 year old coppices) is accompanied by an insignificantly lowered distance to the final F5 (table 1). The vector between the F2 and F3 communities is, however, rather long: 111.67 and is angled 353°. And this means an acceleration of the carabid community development: the SCP index value is on the increase, for the cost of MIB. This trend has been caused by the growing dominance of the small forest species in the F3 community: *Calathus micropterus* (dominant – 43.6%), *Leistus ferrugineus* (15.7%), as well as the large species *Pterostichus niger* (5.3%) – the latter has replaced the 9.2% noted *Carabus arcensis* from F2. In the same time in the F3 community new, even though not frequent, species occurred: the largest zoophages *Carabus glabratus* and *Carabus violaceus.*

The further transformation of F3 into the next stage F4 of 25-42year old stands is described by the vector of 148 units length that is directed at 74.5° angle. An angle larger than 45° gives evidence for larger increase of the MIB index values as compared with SCP. The latter grows slowly, reaching its maximum. The share of individuals belonging to forest species and large zoophages has increased. On the other hand, the portion of the autumn developmental type representatives has become lowered. The following species were dominants:

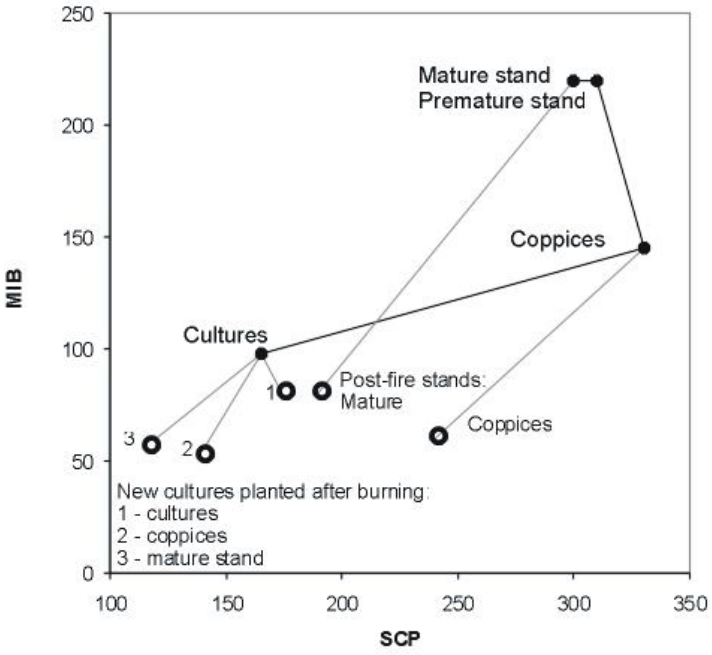

Fig. 4. The effect of unevenaged forest stands fires on their Carabidae communities in Ostrow Mazowiecka

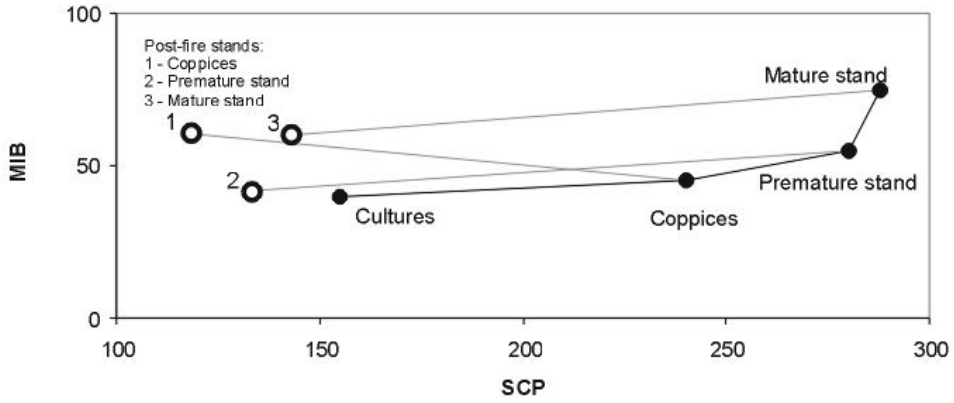

Fig. 5. The effect of unevenaged forest stands fires on their Carabidae communities in Solec Kujawski

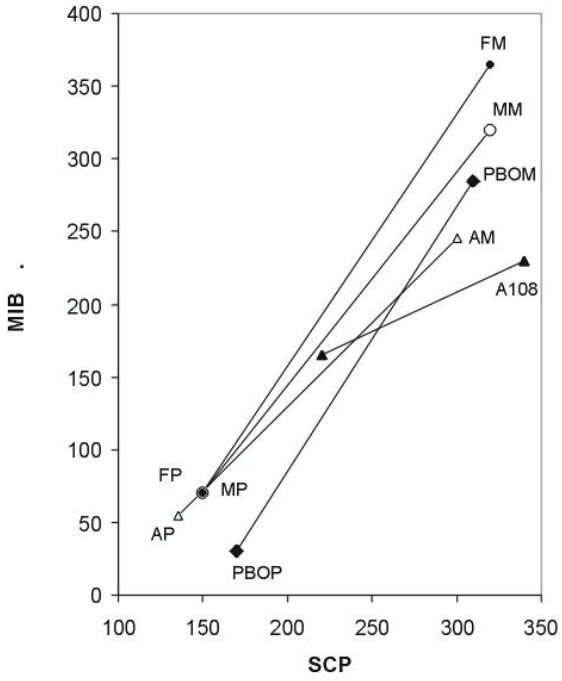

Fig. 6. The response of Carabidae to the clearcut of the mature stands; Carabids community inhabiting mature stand are placed on the right upper side of the SCP/ MIB model, Carabids community inhabiting clear-cut area and cultures are placed on the left side.

C. micropterus (47.6%), *C. violaceus* (15.4%), *C. arcensis* (9.4%), *Pterostichus oblongopunctatus* (6%) and *C. glabratus* (4.3%). As the majority of them are large zoophages, the MIB index value has increased.

The further step in the development process of the carabid communities is the transition of the F4 community into „F5"; this transformation is described by the vector of length equal 143 units, angled at 92°. And this means reduction in the SCP index value, and a respective increase in the value of the other index MIB. The dominant species in this stage were mainly large zoophages: *C. arcensis* (28.6%), *C. violaceus* (23.5%), *C. micropterus* (14.9%) and *C. glabratus* (10.2%).

It can be concluded from the analysis of the above presented model's output that, the initially fast development of the carabid communities in the forest stands established on the post arable ground, becomes slowed in the premature stands down the level making these communities unable to finally (at the stage of the mature forest stand) reach the same developmental level that is reached by the forest ground area carabid communities.

The effect of unevenaged forest stands fires on their Carabidae communities

The solid lines denote the development of the Carabidae communities inhabiting the control forest stands of Ostrow Mazowiecka (Fig.4) and Solec Kujawski (Fig.5). In Solec Kujawski, an extremely low values of the MIB index were recorded in the Carabidae communities studied (Fig.5); this has been the effect of the very poor sandy soils presence on the study area. Because of the low MIB values, the combined SCP/MIB characteristic in Solec Kujawski was flattened (Skłodowski 1994b).

This constatation suggests the need to consider also the trophic characteristic of the site in the construction of the model. Figs 4 and 5 show also the post fire regression process of carabid communities. This is determined by the vectors directed to the left towards the low values of both the indices. The older was the forest stand prior to fire, and the more severe was the fire itself, the longer is the distance between the control and the post fire community. And this means that the fire caused destruction of carabid communities is bigger if the burnt forest was older and if the damaging factor itself (fire intensity) was stronger. This conclusion is confirmed by the study of Szyszko (1983).

The response of Carabidae to the clearcut of the mature stands

The consequences of felling the old-growth forest stands are presented in Fig.6. The symbols used in the graph denote different carabid communities: „FM" – mature forest stand on originally forest ground (site); „MM" – the model stand (compiled following the results of observations carried out in 224 research plots - Szyszko 1983, 1990, Szujecki et al. 1983, Skłodowski 1995a), „A108" - 108-year old forest stand on post arable ground; and "AM" – the mature, 98-year old stand on post arable ground, "PBOM" - the mixed pine-beech-oak stands. The vectors obtained for the stands are all downward

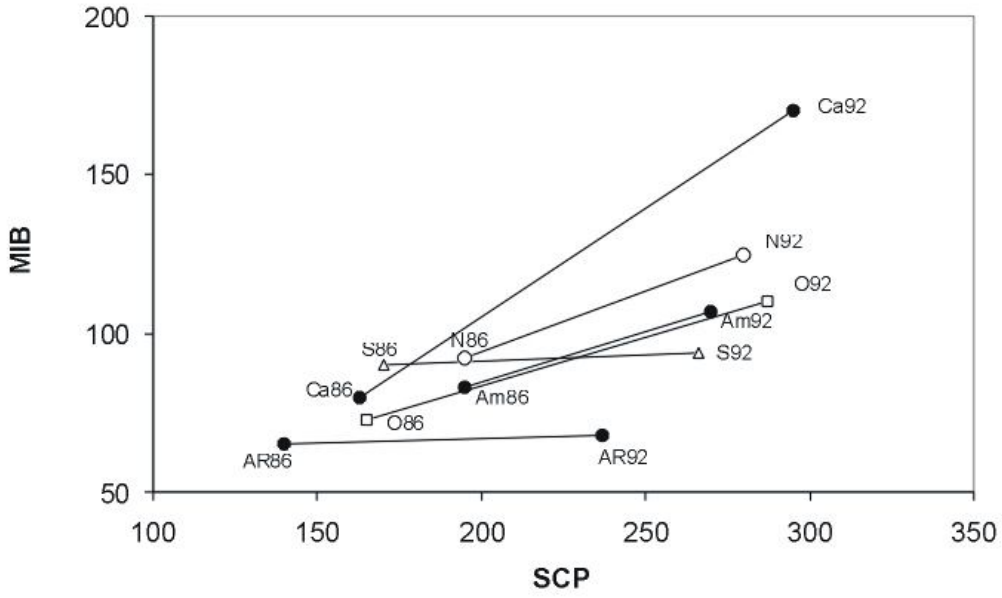

Fig. 7. The effect of fertilization, liming and soil acidification of the soil of the old coppices on Carabidae communities. Explanation of abbreviations please see in the text.

directed and to the left – towards the low values of SCP/MIB, that is the location of those Carabidae communities inhabiting the newly established forest cultures.

The longest vector: 321.69 was fund in the group of Scots pine stands growing on the forest sites ("FM" and "FP"), then in the model stands ("MM" and "MP"): 299.069, then in the mixed pine-beech-oak stands ("PBOM" and "PBOP"): 272.98, then in the group of 98-year old stands on post arable ground: 238.4 ("AM" and "AP"). The shortest vector: 141.1 was that drawn for the 108–year old forest stand established on post arable ground. "The loss" of the Carabidae communities seems the higher (that is the vector is longer), the higher was the successional stage reached by the community at the phase of old-growth forest stand; this conclusion is in agreement with the observations of Szyszko (1990).

Development of carabid communities living in a Scots pine coppice subject to fertilization, liming and soil acidification

Fig. 7 presents the development of carabid communities in a 10-year old coppice that was subject to study in the years 1986-1989 and then 1991-1992 (Sklodowski 1994, 1995b). The intensive height increment and reaching the crowns enclosure is the period of intensified transformation of the non forest fauna into the forest one. An attempt was made to either accelerate the process (by fertilizing the soil) or to hamper it (by acidifying the soil). The initial coordinates of the vectors were determined based on the mean values from the first 4 years of study, when the dosages of applied chemical compounds were equal the standard then doses used in regular soils fertilization. The ends of the vectors are situated on the right region of the SCP/MIB model graph. Their coordinates were calculated as the mean values from the period 1991-1992, when the applied dosages were 4 times bigger, in order to enforce the stronger response of the ecosystem and the carabid communities in particular, to the applied chemicals (Sklodowski 1995a, b).

In the period 1986-1992, the fastest rate of development was observed in the carabid community living in the limed area. The „Ca86"-„Ca92" vector proved to be the longest (156.6 units) and directed at the largest angle: 31°6'. The area of the rectangle built on the vector (the latter treated as the diagonal) was also the largest: 10 854 SCP/MIB units. The control vector „O86"-„O92" was shorter: 131.6 units and was directed

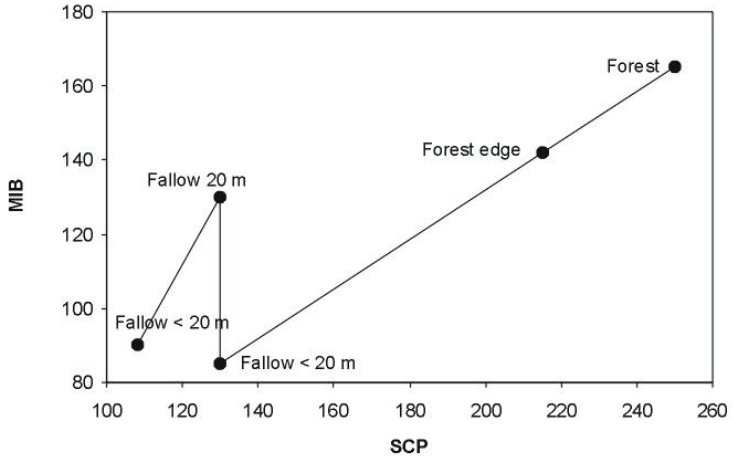

Fig. 8. The status of carabid communities living in different zones of the forest – fallow ecotone.

at the angle of 16°48'. The area of the rectangle was 4788. The fertilization with nitrogen „N86" – "N92" (carbamide) and „Am86" – "Am92" (ammonium) had also accelerated the development of Carabidae. The increase in the dosage of fertilizers had hampered the carabid communities development: the respective vectors lengths were shorter than those of the control: „N" – 84.9 units, angle 15°, area 1804, „AM" – 80.08, angle 15°5', area 1694.

The worst was the effect of soil acidification with use of sulfuric acid for the development of the Carabidae communities „AR" (acid rain simulation) as well as the dry deposition of sulfur "S". The vectors obtained were not only the shorter as compared with the control, but besides they run nearly parallel to the SCP axis: „AR86" – "AR92" – 90 units, angle 0°06', area 180, „S86" – "S92" – 102.2 units, angle 3°54', area 714.

The status of carabid communities living in different zones of the forest – fallow ecotone

The SCP/MIB model (Fig. 8) shows Carabidae communities in a number of ecotone zones of the old growth forest (Scots pine forest type) and of 3-year old fallow land (Skłdowski 1995d). The best indices values of SCP/MIB were characteristic of the carabid community inhabiting the pine forest, somewhat less advantageous than those calculated for the community from the ecotone zone. The communities located in the zones more distant from the forest stand were composed of still more and more numbers of non forest species. The community studied in the fallow land 5 meters from the stand edge has been constituted mainly by non forest pioneer species and was characterized by very low values of the both indices. The MIB index value increase as fund in the fallow community distant 20 m from the stand edge has been connected with the frequent occurrence in that zone of a large open area zoophage *Broscus cephalotes* (Sklodowski 1995d).

SUMMARY

The SCP/MIB model, describing the undisturbed development of carabid communities, is illustrated by the high values of the two indices. Any change in a Carabidae community, caused by the stress and disturbance, makes the SCP/MIB model graph showing lines under angle and directed towards the low values of either index (Sklodowski 1994b, 1995a, 1995b, 1995c). The specific positions as shown in the SCP/MIB model, occupied by particular carabid communities denote different dominant species.

The model described in this paper (or the MIB index alone) has been many times used in the zooindication studies of the condition of forest environment. The studies results have confirmed the correctness of the model's main assumption. This model seems a proper tool that should be included as the basic one for the valorization of forests with use of carabid communities, because of its sensitivity. Even if one of the original indices did not reach the proper value in some situation, the other fulfilled its aim efficiently. As a result, by considering both the regression vector and its angle, one may use (as shown in chapter 3d) the area of the rectangle created on the vector. The larger the area of the rectangle, the deeper are the changes in the carabid community under study. Thus, the model supplies the researcher with a valuable research tool useful in the interpretation of the developmental status of carabid communities.

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